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EQUALIZATION OF WASTEWATER FLOWS

by

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Michael D. LaGrega

Research Division

O'Brien & Gere Engineers, Inc.

Syracuse, New York 13201

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The study was conducted at the Newark, New York Water Pollution Control Facilities during 1970-71. These facilities were modified to permit operation of the plant under either constant or variable flow. (EPA)

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ABSTRACT

The diurnal variability of water flow and waste strength entering treatment facilities has important ramifications in the design and operation of both conventional and advanced waste treatment plants. Plants capable of handling daily average flow may be overloaded with respect to hourly flows. Typically, plants are designed on a basis of this daily average and as such do not always meet the demands of the incoming waste.

This report presents the results of a full scale (2 mgd) study of the effects of maintaining a constant flow of wastewater into a sewage treatment plant through the use of an equalization tank. The study was conducted at the Newark, New York Water Pollution Control Facilities during 1970-71. These facilities were modified to permit operation of the plant under either constant or variable flow.

Preliminary work conducted with mathematical models and bench scale pilot plants operating under a constant flow condition have indicated that improvement in treating efficiency could be expected with such a flow. This study investigates the phenomena on a full scale waste treatment plant.

This report was submitted in fulfillment of Project Number 17090 EEV, Contract Number 14-12-598 under the sponsorship of the Office of Research and Monitoring, Environmental Protection Agency.

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SECTION I. CONCLUSIONS

1. The simple concept of pumping continuously at a steady rate from a holding tank may not always be a successful method of flow equalization. Achievement of an equalized flow at the Newark plant was accomplished by forecasting the daily flow profile to permit use of an equalization tank of reasonable size. A forecasting model was developed using the Box-Jenkins approach and was found to be adequate for establishing an equalized flow rate.

2. The measurement data indicate that a reduction in diurnal variability and maximum concentration occurs in the equalization tank. The coefficient of variation was reduced by approximately 50 percent for BOD_5, COD, TOC and suspended solids. Equalization over a 24-hour period had little effect on the day-to-day variability of the waste strength, except that the variability of suspended solids and volatile suspended solids increased across the equalization tank. This might be attributed to the day-to-day variation in the biological activity in the equalization tank.

3. The measurement data indicate that the equalization of raw wastewater under aerated conditions did not necessarily decrease the BOD in the wastewater. The effluent from the equalization tank showed a small increase in the mean value of BOD, COD, TOC and suspended solids measured on daily composite samples. For the diurnal sampling programs, unfiltered BOD_5 was the only contaminent that showed an increase (15 percent) in mean value across the equalization tank, whereas suspended solids decreased by 19 percent.

4. The measurement data indicate that equalized flow through primary settling tanks resulted in a consistent, normally distributed effluent strength. Equalization of flow prior to primary settling tended to equalize the waste strength in the primary effluent. However, comparison of primary effluents was complicated because activity in the equalization tank caused the influent to the primary tank to differ significantly from Phase 1 (normal flow) to Phase 2 (equalized flow). For the diurnal series, the mean values of BOD_5, COD, TOC, suspended solids and volatile suspended solids in the primary effluent were lower for the equalized phase (suspended solids average removals were 23 percent under normal flow and 59 percent under equalized flow).

5. The standard deviation of the diurnal primary effluent data was lower in Phase 2 for BOD_5, COD, TOC, suspended solids and volatile suspended solids. In the case of BOD_5 and suspended solids, the ratio was 4 to 1. The spread of data in Phase 1 was characterized by a bi-modal distribution, indicative of high values during the day and low values at night. The spread of data in Phase 2 was characterized by a near-normal distribution, indicative of a more consistent feed to secondary treatment. This phenomenon was not exhibited by the daily composite data.

SECTION II. RECOMMENDATIONS

This study represents the first full-scale research effort into flow equalization. As such, many of its findings require further analysis. This study has generated many new questions, as is typical of initial research efforts. It has also identified certain pitfalls that should be avoided in future flow equalization studies.

1. The Newark plant was essentially a new plant when this study was performed, and, as such, was susceptible to many of the startup and operational problems that occur in getting a new plant to achieve normal operation. Any future full-scale flow equalization study should be conducted at a well established plant with a number of years of good operations. This is absolutely necessary.

2. To insure a valid comparison between normal flow and equalized flow, it is strongly recommended that a parallel procedure of plant operation allowing multi-train experiment be used. Suggested flow schemes are:

   a. Equalization before primary units

   b. Equalization after primary units

   c. Equalization without primary treatment

   d. Off-line equalization

   e. Returning sludge to the equalization tank and promoting growth in it

   f. Equalization followed by physical-chemical treatment.

3. On any future equalization projects, a separate equalization tank should be designed and built, rather than just modifying some existing excess capacity facility to handle this purpose. Certain capabilities, such as aeration facilities, could be designed into the equalization tank.

4. The sludge bulking problem that occurred during the equalized flow phase of the project makes impossible any analysis of the effect of flow equalization on the activated sludge process. Additional study should be undertaken to determine the effects of flow equalization on secondary treatment.

5. Information is not yet available on how much of a diurnal variation (percent change) can be allowed before the anticipated benefits of equalization are lost. It should be determined how much of a step change can be tolerated by various treatment systems. If a gradual change of flow can be substituted for a step change, it would be desirable to know what effects would be produced.

6. Methods for predicting wastewater flow rates should be investigated. Possibly, simpler methods can be developed rather than using a sophisticated mathematical model as was done on the Newark study.

7. Possible changes occurring in the wastewater concentrations in the equalization tank should be characterized. Because of the necessity of controls, consideration should be given to conducting these evaluations on pilto scales. Ideally these would be carried out at the treatment plant concurrent with the full scale studies.

8. There is a need for cost estimating with respect to flow equalization, i.e., is the additional cost of equalizing flow worth the anticipated improved removals?

9. Consideration should be given to conducting a series of experiments to determine the relationship between surface overflow rate and suspended solids removal under constant flow conditions.

10. Consideration should be given to examining the response of the activated sludge process to organic loading under constant flow conditions.

SECTION III. INTRODUCTION

The diurnal variability of flow entering the wastewater treatment facilities has important ramifications in the design and operation of both conventional and advanced waste treatment plants. Conventional treatment plants are necessarily designed hydraulically to handle peak flows. Savings in capital investment would be realized if one could plan for peak daily flow rather than the peak hourly. This point is especially significant in the case of either small or combined systems.

The operation of existing plants is affected by variable flow. Plants capable of handling daily average flow may be overloaded with respect to hourly flows. Typically plants are designed on a basis of this daily average, and as such do not always meet the demands of the incoming waste. Temporary overloading has a deleterious impact on treatment efficiency and hence on receiving waters. For instance, the efficiency of a biological unit in secondary plant can be severely impaired by shock hydraulic loads. This is well established in a number of existing plants where by-passes are incorporated around the biological units.

Many advanced waste treatment schemes are adversely affected by the flow variation. For example, the solids-contact process utilized for chemical precipitation of solids and phosphorous removal, is extremely sensitive to a variable flow. The constant feed of chemicals would provide better control and balance in precipitation and coagulation processes. Carbon adsorption is more effective if hydraulic loadings are uniform. With diurnal flow variation, design and operation can be rendered more costly, and some advanced treatment methods become infeasible.

The central assumption underlying this study is that a potential solution to these problems is equalization of wastewater flows. A flow is said to be equalized if it is more or less constant with time. Thus, in its simplest form, equalization is often conceived to be attainable by use of a properly designed holding tank, from which wastewater is pumped to the treatment facilities, at a constant rate. The actual situation is complicated by the variation in flow from day-to-day. Because of this it is necessary to be able to predict flows in order to adjust the rate at which wastewater is pumped from the equalization tank. This must be done in order to prevent overflowing or emptying the tank.

The equalization of wastewater flows would be expected to provide numerous benefits. Certain tertiary treatment schemes require a relatively constant flow. Hence, equalization would be necessary for these methods. All units in the plant would probably benefit if the equalization units were placed ahead of the raw flow. New plants could be designed for day-to-day variations rather than the hourly patterns currently incorporated into empirical criteria. Increased efficiency would be expected in existing installations by the elimination of temporary peaks. It is believed that the addition of equalization tanks will eliminate the need to by-pass peak flows.

In addition, equalization of raw flows would be expected to reduce influent BOD if aeration were used for mixing in the equalization tank; to be useful in treating flows from combined sewers; and to reduce the impact of shock loads from industrial wastes.

This research was undertaken in order to determine how to effect equalization of flows; to physically demonstrate equalization on a full scale basis; and to study the effects on treatment efficiency. In addition, a significant review and evaluation was to be made of the definition, the concept, and the physical implementation of equalization.

SECTION IV. EXPERIMENTAL METHODS

DESCRIPTION OF FACILITIES

The sewage treatment plant at Newark, New York was selected for a full-scale study of flow equalization. This conventional activated sludge plant treats an average flow of approximately 1.8 mgd. A schematic diagram of the plant is presented in Figure 1.

Laboratory facilities were installed at the Newark plant to facilitate data collection. This laboratory included atuomatic sampling devices, equipment for performing BOD and suspended solids analyses, controls for the pumps and monitoring equipment to record raw and equalized flows. The equalization facilities which were constructed and installed at the plant included a constant head box, pumps, magnetic flow meter, and associated piping and valves.

PHASE 1

This portion of the study was devoted to characterizing plant operation during normal flow conditions. Ordinarily, the plant utilizes two primary sedimentation tanks, two aeration tanks and two secondary clarifiers, achieving efficiencies of 85 percent to 95 percent BOD_5 and 80 percent to 90 percent suspended solids removal. In order to reduce these removals so that any changes in plant efficiency could be related to flow equalization, only one of each unit was utilized. Thus, the loading was effectively doubled for the purpose of this Study, reducing the plant to what were termed marginal operating conditions (secondary removal of 65 percent SS and 80 percent BOD_5).

PHASE 2

During this phase, the raw flow was diverted to the second aeration tank which was used solely as the equalization tank during this study (see Figure 1). The sewage was then pumped to a constant head box from which it flowed by gravity at a constant flow rate to the primary settling tank, the excess overflowing back to the equalization unit. The flow from the constant head box was regulated by a plug valve and measured with a magnetic flow meter. The total volume of the equalization tank was 412,000 gallons with an effective depth of 12 feet. The raw sewage in the equalization tank was aerated to prevent sedimentation and avoid septic conditions. This phase was also made to operate at marginal efficiency as in Phase 1.

FLOW MODELING

The stochastic nature of the wastewater flow made it necessary to develop a forecasting model for predicting the daily flow profile in order to accomplish equalization. The forecasting model was constructed from the collected data, which had been reduced to hourly flow rates, following an iterative procedure consisting of identification, estimation and diagnostic checking.

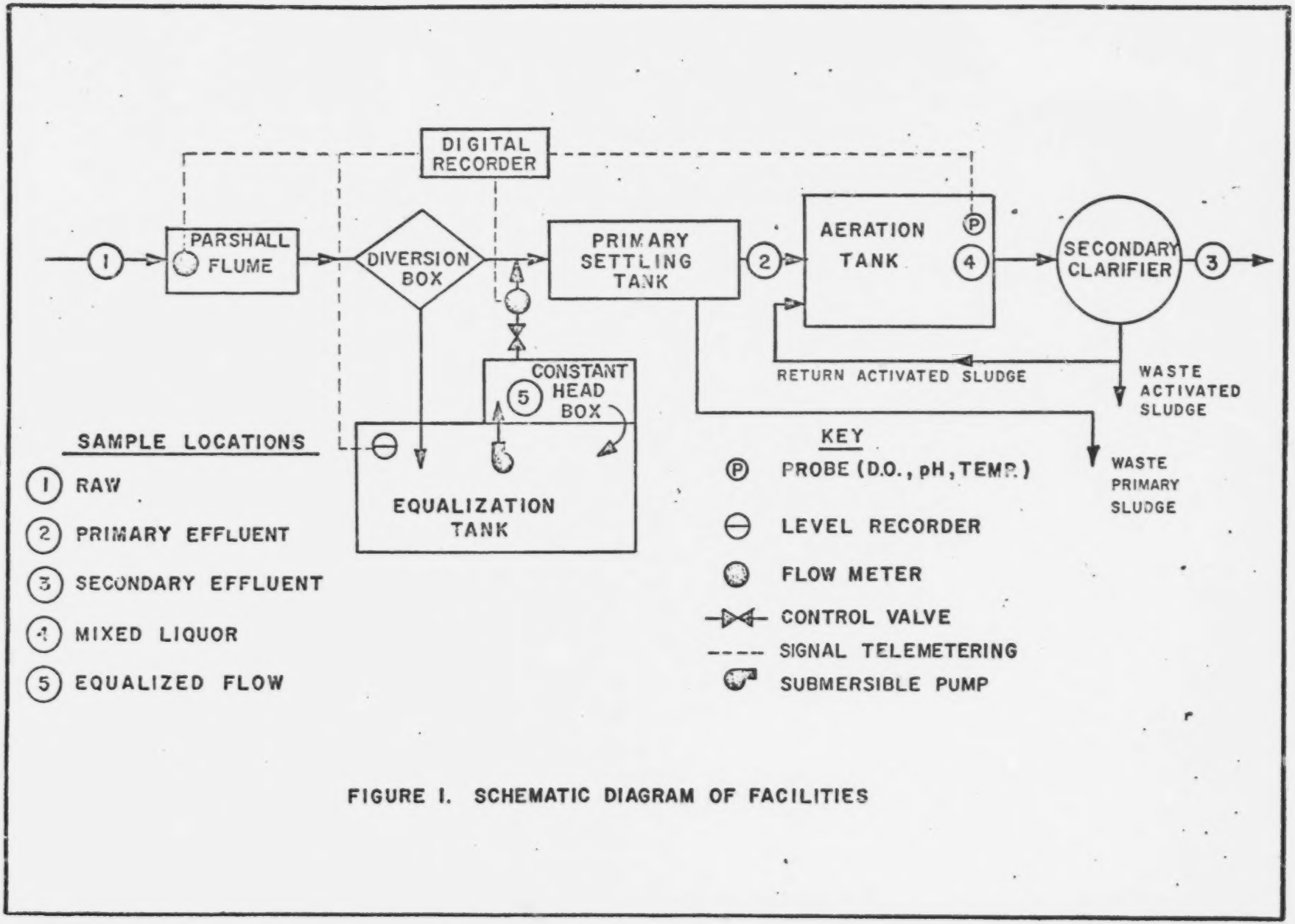

FIGURE I. SCHEMATIC DIAGRAM OF FACILITIES

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Identification consists of determining the type of model (e.g., a sine function) best suited to the data. This is followed by estimation of the parameters of the model (e.g., the amplitude, period and phase angle of the sine function). Diagnostic checking then determines how well the model is able to predict actual data. The actual model developed for this case was an autoregressive-integrated moving average model.[9]

The primary tools for identification used in this Study was the sample autocorrelation function of the original series and its differences. This indicates the way the current reading relates to the previous readings, providing information about the nature of the model, indicating seasonal patterns, and determining if the model is stationary (i.e., does the mean value remain relatively constant with time, or does it continually increase).

The second step, of fitting the tentatively identified model was accomplished by utilizing a non-linear least squares method to estimate the parameters (unknown coefficients). Finally, diagnostic checking was accomplished by examining the autocorrelation function of the residuals (actual data–forecast value). If the model is adequate, the residuals behave randomly; if not, some pattern will show up in the residuals and an analysis of this pattern indicates how the original model should be modified to improve the fit. The iteration then begins again at the first step with the modified model. The method adopted here is the one recently proposed by Box and Jenkins.[9] Details of this will be reported elsewhere (Goel & LaGrega, 1972).[35]

This model was utilized to predict the raw flow values and from these an equalized flow settling was determined. A sample comparison of the actual and forecasted flows is shown in Figure 2.

OPERATING PROCEDURE FOR USING THE FLOW MODEL

Equalized flow settings were changed each day at 3:00 p.m. The previous 24 hourly flow readings and current tank level were telephoned to a computer operator at a nearby facility. This information was added to the previously stored flow data and flows for the next 24 hours were predicted, using the forecasting model developed earlier.

The predicted flows were then input to a simulation routine which would determine the equalized flow setting. The objective of the simulation program was to obtain a level of 1 foot (i.e., near empty condition) in the equalization tank at 6:00 a.m. the following morning. This is approximately the time when the flow rate profile would cross a horizontal line at the average daily flow. This can be seen in Figure 4 by noting the sharp rate of increase in the flow at approximately 6:00 a.m.

This computer program would also list projected tank level so that changes to be made in the equalized flow setting could be determined by observing this level the following morning. When required, the equalized flow was set at the new value in the morning. The computer costs of this procedure were nominal, amounting to a few dollars per day.

Equalized flow readings for the diurnal sampling period are shown in Figure 3. Since research personnel were on site around the clock during these three days it was possible to change the equalized flow setting at arbitrary times. The step increments required to

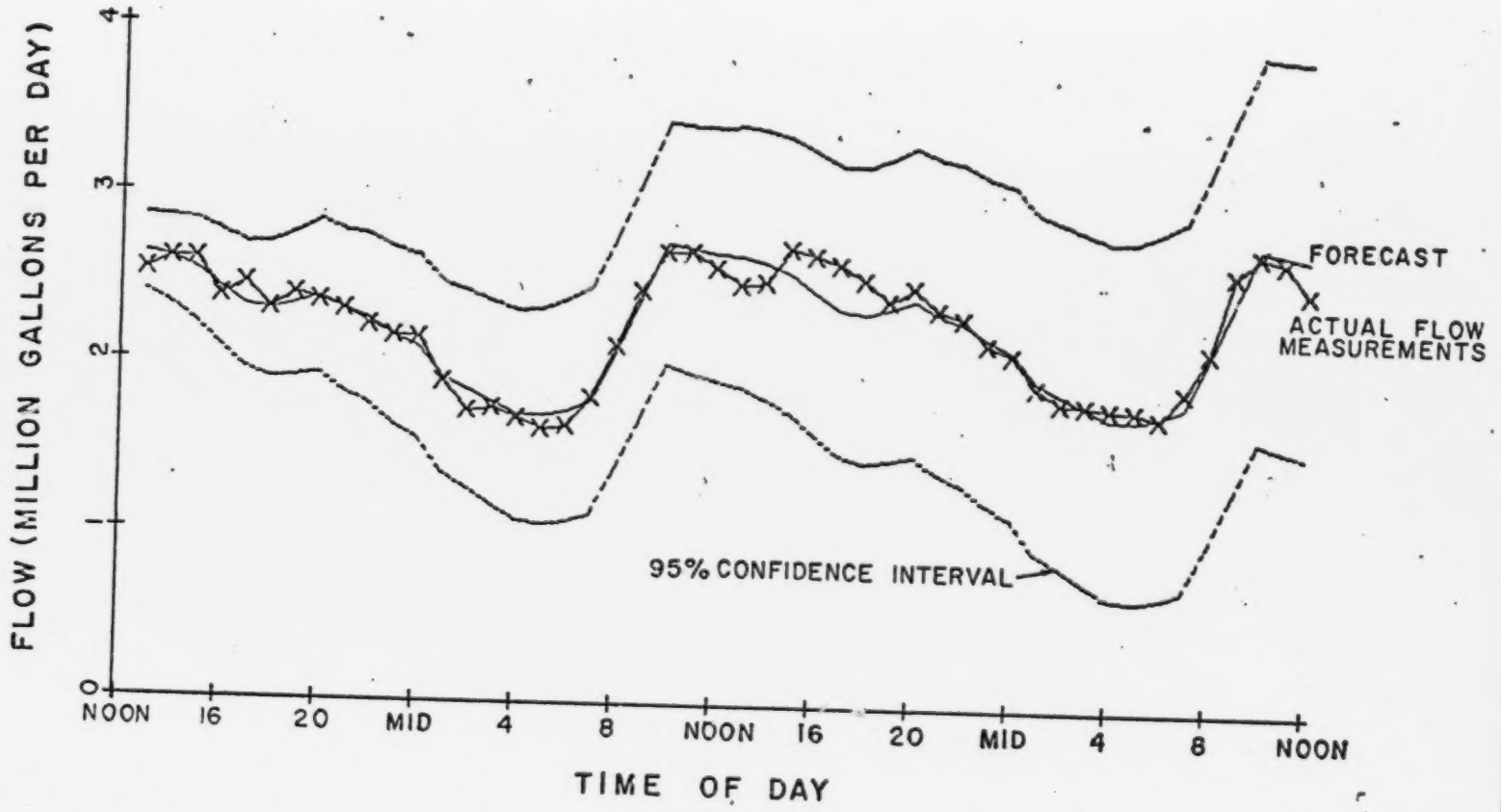

FIGURE 2 SAMPLE COMPARISON OF ACTUAL AND FORECASTED FLOWS

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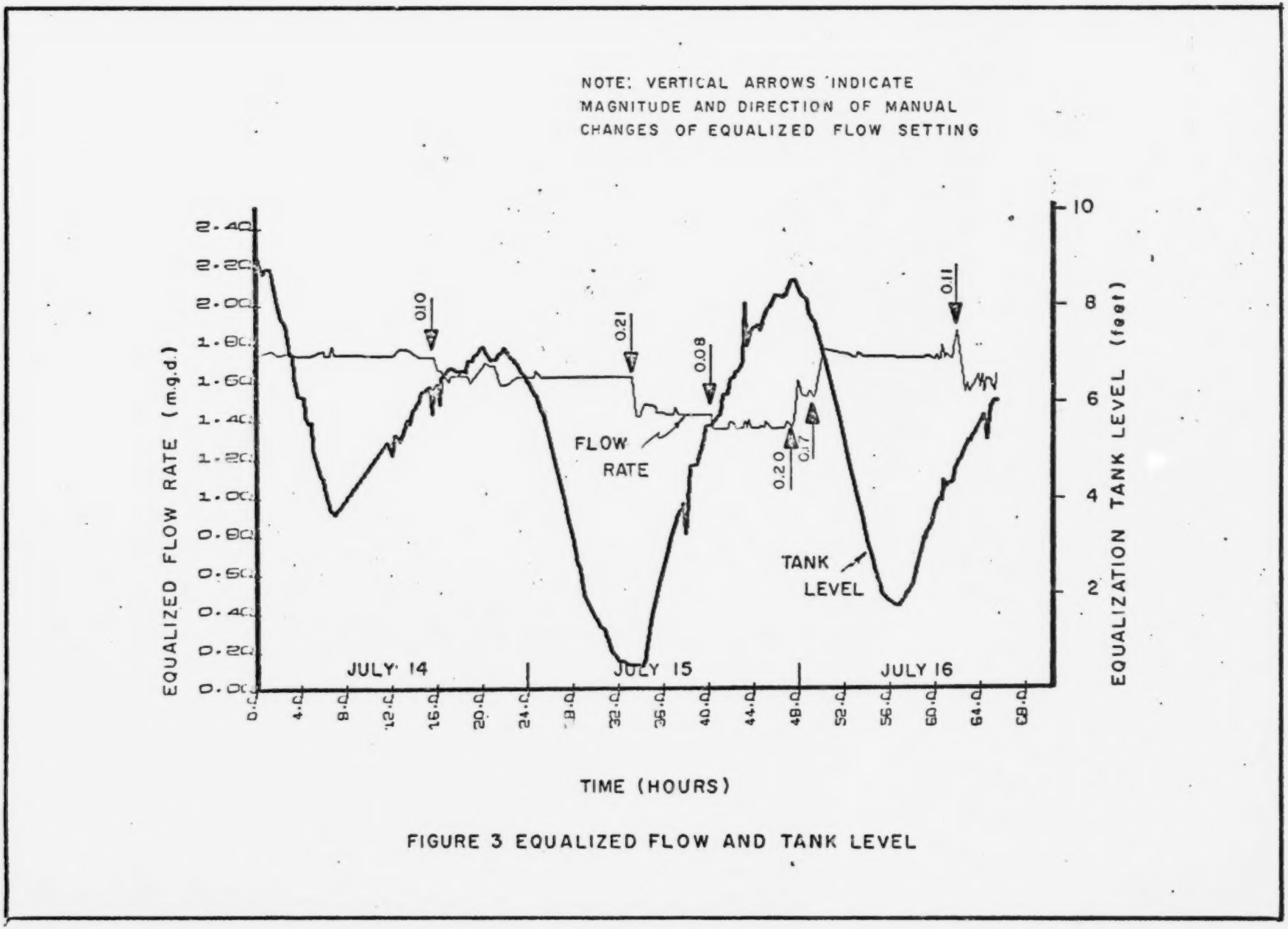

FIGURE 3 EQUALIZED FLOW AND TANK LEVEL

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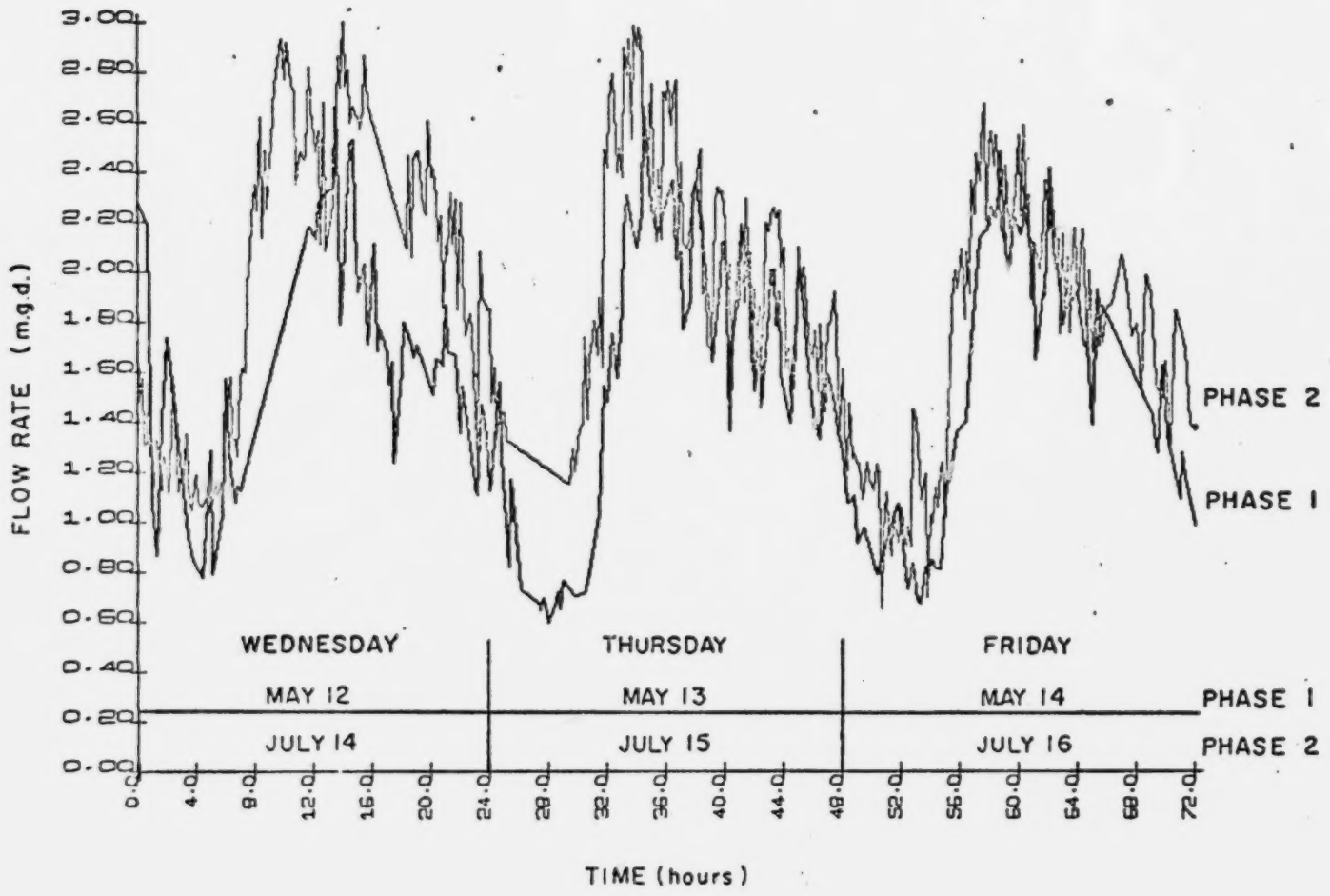

FIGURE 4 COMPARISON OF RAW FLOWS

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maintain constant flow were in the order of 10-20 percent. No attempt was made in this study to ascertain how small such increments must be to obtain an "equalized" condition.

The level in the equalization tank is also shown in Figure 3. This illustrates that the capacity of the tank is not fully utilized in actual operation. This is due to the fact that the minimum tank size required to just maintain equalized conditions varies from day to day due to the stochastic nature of the flow. This will have a significant effect on the design of equalization facilities. It should be noted that both curves in Figure 3 are computer plots of data collected by the digital recorder and show considerable "noise" due primarily to the paper tape punch utilized.

SAMPLING REGIME

Two sampling programs were developed for use in this Study. Daily composite samples were taken during each phase. These samples were collected by Sigmamotor composite samplers which delivered a constant volume at preset constant time intervals. All analyses were performed in accordance with the 13th Edition of Standard Methods[52] except for the omission of duplicate weighing in the determination of suspended solids. The analyses performed are listed in Table 1. Samples collected for COD, TOC and nitrogen analyses were preserved with concentrated sulfuric acid. BOD, COD and TOC analyses were performed on both filtered and unfiltered aliquots. The filters used were glass fiber filter pads (Reeve Angel 934 AH).

Readings of temperature, dissolved oxygen, and pH of the aeration tank, raw flow, equalized flow and equalization tank level were taken every ten minutes and recorded on punched paper tape, along with a test signal to check instrumentation and the time and date. The instrument utilized for this was a Robot Monitor manufactured by the Schneider Instrument Company.

A regression model, using a Stepwise Mutiple Regression,[22] was developed to predict BOD_5 as a function of COD, and TOC, as it was not possible to conduct all of the BOD tests required by the diurnal sampling program. The technique of power transformation was also investigated, and the results of this work will be reported in depth elsewhere (Goel & LaGrega, 1972).[36]

Samples from the equalization tank, aeration tank and secondary clarifier were examined microscopically for the presence of protozoa and filamentous organisms. The identification of filamentous organisms was based on Breed *et al* (1957)[12] and Farguhar and Boyle (1971).[30] The presence of sheaths was determined by staining with crystal violet and methylene blue and by the lysozyme-detergent treatment recommended by Farquhar and Boyle (1971).[30] The Prussion blue reaction was used to evaluate the ability of the sheaths to oxidize ferrous iron. The ability of the organisms to oxidize and deposit manganese was evaluated by plating onto manganese agar (Pringsheim, 1949).[77]

TABLE 1

ANALYSES PERFORMED

Biochemical Oxygen Demand (f)	Orthophosphate
Chemical Oxygen Demand (f)	Total Phosphate
Total Organic Carbon (f)	Total Organic Nitrogen
Suspended Solids	Ammonia Nitrogen
Volatile Suspended Solids	Nitrate Nitrogen
Total Solids	Nitrite Nitrogen
Volatile Total Solids	pH

(f) - Analyses also performed on filtered aliquots

SECTION V. FIELD PROGRAMS

PHASE 1 PROGRAM

Phase 1 of the Study was conducted from April 3 until May 14, 1971. During this phase, the plant was operated under a normal flow pattern, but with the loading increased as previously noted. The intent was to operate the plant at marginal conditions defined roughly as 65-85 percent removal of BOD_5 and suspended solids. The mixed liquor suspended solids averaged 2,000 mg/l and the sludge volume index was variable, but consistently well below 100. The surface overflow rate for this period was approximately 1,000 gallons per day per square foot.

During the last two days of Phase 1, May 12-14, 1971, a detailed diurnal sampling program was conducted. Composite samples were collected on a one or two hour basis around the clock, the more frequent sampling period coinciding with periods of greatest change in flow rate. In addition to the five main sampling points, periodic samples were also collected of the digester supernatant, waste activated sludge, and centrate from the solids dewatering operation. Two samples per day were collected of the digester contents and primary sludge.

The time of collecting samples at the major sample points (Figure 1) was lagged to allow for detention time in the various units. This permitted more accurate evaluation of the diurnal characteristics of treatment efficiency.

PHASE 1 RESULTS

Mean values of data for this phase under normal flow pattern are presented in Table 2. It is particulary interesting to note the poor removals achieved in primary treatment, for all of the parameters shown. In editing the data, values corresponding to negative removal efficiencies were deleted.

Secondary removals were 63 percent for suspended solids and 80 percent for BOD_5, indicating that the plant was operating marginally. COD removals were lower than BOD_5 removals (70 percent) as would be expected. Soluble organic carbon (filtered TOC) was reduced only 54 percent, but is is difficult to evaluate whether this is typical or not, since no standard or generally accepted values exist.

Mean values of data collected during the diurnal sampling program are presented in Table 3. These values represent weighted arithmetic means, the weights being proportional to the raw flow rate at the time of sampling, and therefore representative of mass and not concentration. Concentration units were utilized to permit comparison with typical or anticipated values. It should also be noted that average BOD_5 and BOD_f values do not include regressed values, but only those actually measured.

The above results indicate good overall removals but rather poor primary removals. The raw waste was stronger during this diurnal series than during the daily series; however, the same phenomenon of poor primary removal was also exhibited. In the diurnal series, removal of BOD_5 approached 90 percent while COD and Suspended Solids removals were

TABLE 2

PHASE 1 - NORMAL FLOW CONDITIONS

SUMMARY OF DAILY DATA

VARIABLE	SAMPLE POINT RAW	PRIMARY	SECONDARY
Biochemical Oxygen Demand	183.9	144.5	37.4
Biochemical Oxygen Demand (f)	109.5	73.2	14.7
Chemical Oxygen Demand	373.3	265.6	113.7
Chemical Oxygen Demand (f)	172.1	110.3	52.8
Total Organic Carbon	105.7	90.9	42.7
Total Organic Carbon (f)	65.5	48.5	30.1
Suspended Solids	143.2	86.4	53.3
Volatile Suspended Solids	120.7	75.9	47.2

Note: Values expressed in units of milligrams per liter.

Data corresponding to negative removal efficiencies ommitted.

TABLE 3

PHASE 1 - NORMAL FLOW CONDITIONS

SUMMARY OF DIURNAL DATA

VARIABLE	SAMPLE POINT RAW	PRIMARY	SECONDARY
Biochemical Oxygen Demand*	237.1	209.6	27.5
Biochemical Oxygen Demand (f)*	108.6	105.0	8.4
Chemical Oxygen Demand	407.2	355.7	96.4
Chemical Oxygen Demand (f)	196.8	224.9	64.9
Total Organic Carbon	115.6	120.5	35.7
Total Organic Carbon (f)	76.6	82.8	32.0
Suspended Solids	136.7	105.4	35.3
Volatile Suspended Solids	120.5	92.6	30.5

Note: Values expressed in units of milligrams per liter.
Data weighted with flow.

*Regressed values ommited.

about 75 percent. Primary removals of BOD_5 and COD were only 12 percent while suspended solids were reduced by 23 percent.

PHASE 2 PROGRAM

At the conclusion of the diurnal sampling program under Phase 1 the plant was converted to an equalized flow scheme. The entire raw waste flow was diverted to an aerated equalization tank. From this tank the waste was pumped to a constant head box and allowed to flow, at a constant rate, to the primary tank (Figure 1). The level in the equalization tank then varied throughout the day, in proportion to the difference between the rates of inflow and outflow.

Initial attempts to affect equalization were hampered by mechanical problems and data collection for the second phase did not begin until June 2, 1971. Concurrent with the start of equalization a sludge bulking condition was experienced at the plant.

Biological examination of the mixed liquor revealed that two filamentous forms, *Sphaerotilus natans* Kütz and *Vitreoscilla sp.* were present with *S. natans* clearly being the dominant form. There were no filaments in the equalization tank. There was, however, definite biological growth in the equalization tank, best described as activated sludge floc-like particles. The data collected during this Study was not sufficient to properly characterize the relationship between bulking and equalization.

Phase 2 was concluded with a diurnal sampling program identical to that of Phase 1 except that samples were also taken of the equalized flow.

PHASE 2 RESULTS

A summary of data collected during Phase 2 (June 2 - July 16, 1971) is given in Table 4. As in Table 2, these data have been edited by removing values corresponding to negative removals.

Discussion of removal efficiencies for this phase is complicated by the fact that growth in the equalization tank appears to have increased all of the variables measured. As an example, primary removal of suspended solids based on the raw sample of 136 mg/l was only 39.7 percent. But, if the primary efficiency is calculated by comparing what entered the primary clarifier (165 mg/l) to the effluent (85.7 mg/l) the removal efficiency is 48 percent. Any evaluation of the secondary effluent must be qualified by noting the occurrence of the bulking condition previously mentioned.

The diurnal data for the Phase 2 sampling program are summarized in Table 5. In reviewing these data the only substantial difference noted in primary effluent compared to either the raw or equalized sample, is in suspended solids and volatile suspended solids. The average primary removal of suspended solids was 59 percent. If the influent to the primary clarifier is compared with the effluent, the removal efficiency is only 47 percent.

TABLE 4

PHASE 2 - EQUALIZED FLOW CONDITIONS

SUMMARY OF DAILY DATA

	SAMPLE POINT			
VARIABLE	RAW	EQUALIZED	PRIMARY	SECONDARY
Biochemical Oxygen Demand	185.2	193.7	139.3	78.1
Biochemical Oxygen Demand (f)	79.2	89.0	58.1	18.1
Chemical Oxygen Demand	346.5	404.8	280.7	186.7
Chemical Oxygen Demand (f)	139.6	143.7	109.6	58.3
Total Organic Carbon	98.3	112.1	87.3	80.9
Total Organic Carbon (f)	52.4	48.0	44.3	27.2
Suspended Solids	136.8	164.8	85.7	48.6
Volatile Suspended Solids	119.2	137.1	74.5	43.1

Note: Values expressed in units of milligrams per liter.
Data corresponding to negative removal efficiencies ommited.

TABLE 5

PHASE 2 - EQUALIZED FLOW CONDITION

SUMMARY OF DIURNAL DATA*

	SAMPLE POINT			
VARIABLE	RAW	EQUALIZED	PRIMARY	SECONDARY
Biochemical Oxygen Demand*	186.4	219.5	184.9	74.5
Biochemical Oxygen Demand (f)*	91.6	89.4	93.1	18.7
Chemical Oxygen Demand	437.2	405.5	337.5	223.8
Chemical Oxygen Demand (f)	232.8	219.5	214.7	67.8
Total Organic Carbon	120.0	110.2	97.3	74.7
Total Organic Carbon (f)	70.2	65.8	66.4	23.3
Suspended Solids	163.9	128.0	68.0	86.3
Volatile Suspended Solids	133.6	109.9	60.5	76.9

Note: Values expressed in units of milligrams per liter.
Data weighted with flow.

*Regressed values ommitted.

SECTION VI. DISCUSSION

GENERAL

Evaluation of the results of this Study requires first an examination of the two raw flows to validate the experiment by assuring that the raw wastes were comparable. The next comparison to be made is between the raw waste and the effluent from the equalization tank, to determine the effects of equalization of raw sewage. Comparison of primary effluent served to indicate what improvement in removal efficiencies could be anticipated from equalization. Due to the bulking problem in the second phase of the Study, it was deemed invalid to compare the secondary effluents.

COMPARISON OF RAW WASTES

The comparison of treatment with and without equalization requires evaluation of the two raw flows to establish experimental validity. Figure 4 shows that the diurnal flow pattern of these two phases was indeed similar. No attempt was made to describe this similarity numerically, as a subjective comparison of the raw flows was considered sufficient. While the average flow was slightly higher in the first phase, the pattern and magnitude of change were almost identical for the two flows.

A comparison of the sanitary characteristics of the raw waste for the diurnal sampling program for each phase is exhibited in Table 6. The comparisons are based on the t-test[23] using a 95 percent confidence interval to determine whether there are any significant differences in the mean values of the two raw wastes. Table 6 indicates that the difference in the mean values is not statistically significant for any of the variables shown. If only 80 percent confidence in the comparison is required then the differences appear significant for BOD_5 and filtered COD, (the comparisons yielding the highest t-values and hence the most significant difference), are illustrated in Figure 5. Here it is seen that, even for the worst case, there is little difference in the distribution of the raw waste data for the two phases. The maximum value encountered in the second phase was higher than the first (445 compared to 392 mg/l), and the mode of the second phase distribution also exceeded that of the first phase by about the same amount. In summary, for the variable exhibiting the most difference in mean values, filtered COD, it appears that the values during Phase 2 were only slightly higher.

The variable with the next highest t-value is BOD_5, which might be expected to be reasonably well correlated with the COD. However, while the filtered COD values were slightly higher on the average in Phase 2 than in Phase 1, the BOD_5 values show the reverse relationship. Thus, the differences between the two raw flows appear to be random and relatively minor.

The only discernible difference in the raw waste was in the suspended solids and volatile suspended solids of the daily composite samples. While the mean values did not differ, the standard deviations were much larger in Phase 1. No definitive explanation has been found for this. This type of effect could have been precluded through the use of a dual train experiment. Smoothed histograms illustrating this comparison may be seen in the lower graph of Figure 9.

TABLE 6

COMPARISON OF MEAN VALUES OF RAW WASTES

PHASE 1 VERSUS PHASE 2

VARIABLE	PHASE 1 Mean	PHASE 1 Std.Dev.	PHASE 2 Mean	PHASE 2 Std.Dev.	t	ν	95%CONFIDENCE LIMITS Lower	$(\mu_1-\mu_2)$	Upper
Biochemical Oxygen Demand*	237.1	123.8	186.4	130.3	1.16	36	35.2		137.0
Biochemical Oxygen Demand (f)*	108.6	67.9	91.6	58.7	0.70	26	30.3		64.3
Chemical Oxygen Demand	407.2	244.6	437.2	241.2	-0.53	71	-141.0		81.4
Chemical Oxygen Demand (f)	196.8	105.1	232.8	113.0	-1.39	69	-86.8		14.8
Total Organic Carbon	115.6	63.4	120.0	63.2	-0.30	71	-33.4		24.6
Total Organic Carbon (f)	76.7	37.1	70.2	35.0	0.77	70	-10.2		23.2
Suspended Solids	136.7	87.4	163.9	119.2	-1.10	69	-75.7		21.3
Volatile Suspended Solids	120.5	74.5	133.6	92.7	-0.66	69	-52.5		26.0

Data from diurnal sampling program.
Values weighted with flow.

*Regressed values omitted.

t - Student's t - statistic
ν - Degrees of freedom
f - Analyses performed on filtered aliquots

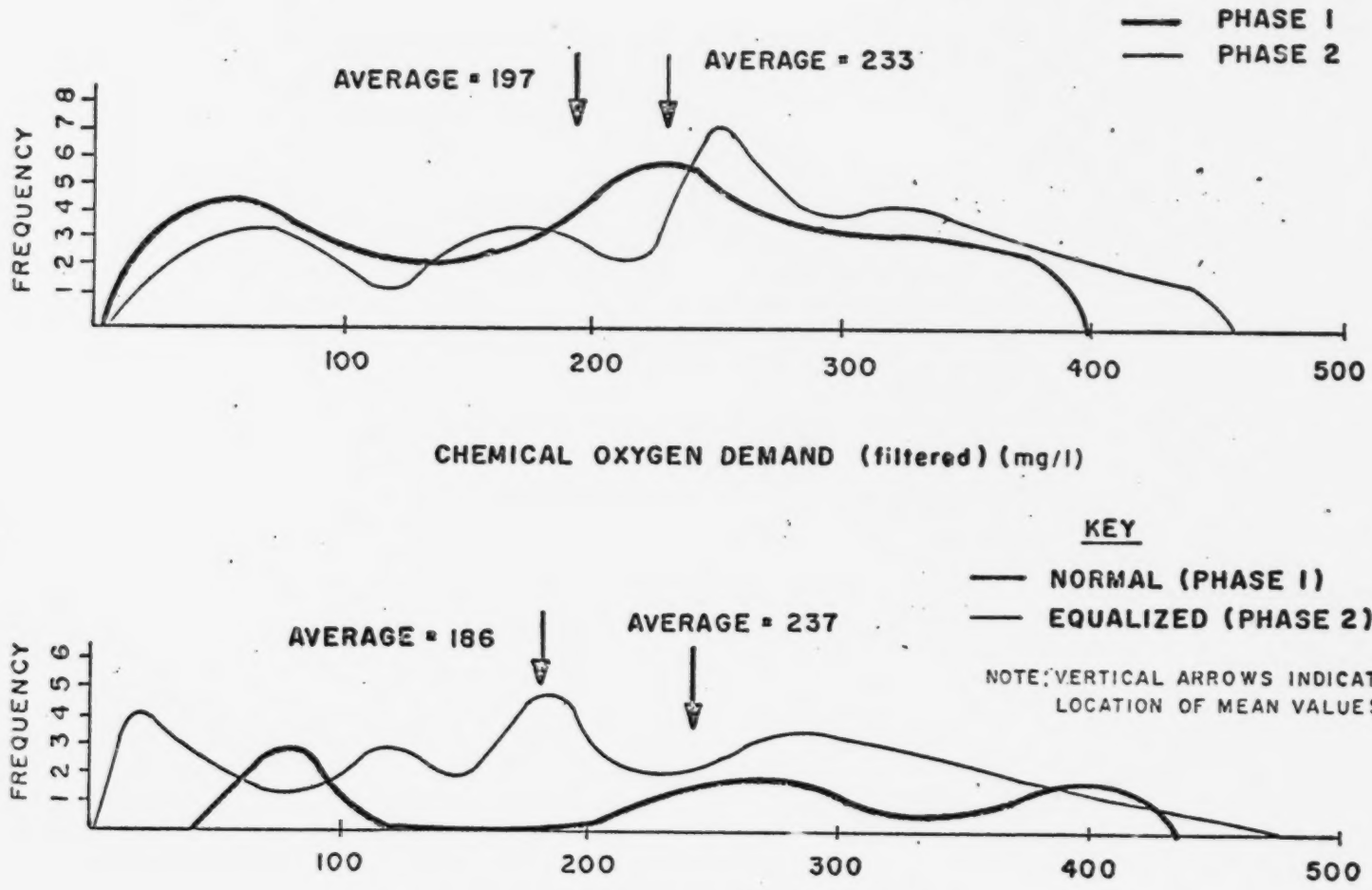

FIGURE - 5 - COMPARISON OF RAW WASTE DATA FROM DIURNAL SAMPLING SERIES

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The daily and diurnal data cannot be directly compared to one another. Each daily sample is a composite which essentially represents average conditions during the day. Thus differences between daily samples are day to day variations. The diurnal series, on the other hand, are collected separately at hourly intervals and different values would be expected at different times. Moreover, average values will not be identical unless, by chance, the day selected for diurnal sampling happens to be the average day in terms of waste strength. Stated differently, the daily samples are from a common population, the diurnal samples are not.

In summary, the data indicate that any differences between the raw waste samples of the two phases were sufficiently minor, so that differences in results could be attributed to the effects of equalization.

EFFECTS OF EQUALIZATION

The next step is to examine the effects of equalization by comparing the influent to the equalization tank (raw waste) with the effluent (equalized flow). A comparison of mean values for the diurnal data is exhibited in Table 7. Data included in this comparison were weighted by flow (the weighting value consisting of flow at time of sample divided by average flow).

In evaluating the data in Table 7, it is noted that the 95 percent confidence interval for $\mu_r - \mu_e$ spans zero for all variables. Thus, there is no discernable difference between the mean values at this confidence level. Even at a confidence level of only 80 percent, only the differences in suspended solids and volatile suspended solids appear significant.

The lower degrees of freedom (ν) for BOD_5 and BOD_f are due to removal of regressed values. (As noted in Section 3, physical limitations precluded running BOD analyses of all diurnal samples.) In examining the mean values of BOD_5 there appears to be a small increase of approximately 30 mg/l across the equalization tank. The t-value (-1.09) indicates about 70 percent confidence in the existence of an increase in diurnal BOD_5. There is virtually no change in the filtered BOD_5, indicating that this is entirely an increase in suspended BOD_5. Chemical oxygen demand appears to decrease by approximately 30 mg/l, again with a relatively low degree of confidence (70 percent).

It is quite definite that changes occur in the waste across the equalization tank, but these data do not characterize them fully. It appears that biological growth in the tank may be causing the increase in BOD_5 and suspended solids.

As noted in the previous section, microscopic examination of the equalization tank contents revealed floc-like particles not present in the raw sewage. Possibly this growth is degrading some of the waste, thereby accounting for the slight decrease in COD, and at the same time converting a larger amount of non-biodegradeable material to more readily biodegradeable forms that are detected in the five day BOD test. The data are clearly open to other interpretations.

The most significant change occurring in the equalization tank is the reduction in diurnal variability of waste strength and lowering of the maximum values. This diurnal variation has been reduced to approximately the day to day level as measured by the coefficient of

TABLE 7

COMPARISON OF MEAN VALUES

RAW WASTE VERSUS EQUALIZATION TANK EFFLUENT

VARIABLE	RAW WASTE		EQUALIZATION TANK EFFLUENT				95% CONFIDENCE INTERVAL		
	Mean	Std.Dev.	Mean	St.Dev.	t	ν	Lower	$(\mu_1 - \mu_2)$	Upper
Biochemical Oxygen Demand*	186.4	130.3	219.5	61.0	-1.09	45	-92.6		26.4
Biochemical Oxygen Demand (f)*	91.6	58.7	89.4	18.8	0.14	30	-28.9		33.3
Chemical Oxygen Demand	437.2	241.2	405.5	117.4	0.69	69	-57.8		121.0
Chemical Oxygen Demand (f)	232.8	113.0	219.5	55.6	0.62	68	-28.8		55.4
Total Organic Carbon	120.0	63.2	110.3	24.5	0.84	69	-13.0		32.4
Total Organic Carbon (f)	70.2	35.0	65.8	15.0	0.68	68	-8.4		17.1
Suspended Solids	163.9	119.2	128.0	56.7	1.53	64	-10.1		81.9
Volatile Suspended Solids	133.6	92.7	110.0	49.1	1.25	63	-13.4		60.6

Data from diurnal sampling program.
Values weighted with flow.

*Regressed values omitted.

t - Students t - statistic
ν - Degrees of freedom
f - Analyses performed on filtered aliquots

TABLE 8

EFFECT OF EQUALIZATION

COEFFICIENT OF VARIATION

VARIABLE	DIURNAL		DAILY	
	Raw Waste	Equalization Tank Effluent	Raw Waste	Equalization Tank Effluent
Biochemical Oxygen Demand*	69.9	27.7	36.5	27.8
Biochemical Oxygen Demand (f)*	64.0	20.9	53.7	34.2
Chemical Oxygen Demand	55.1	28.9	24.4	21.1
Chemical Oxygen Demand (f)	48.5	25.3	28.1	30.2
Total Organic Carbon	52.6	22.2	21.9	23.2
Total Organic Carbon (f)	49.9	22.8	36.9	37.7
Suspended Solids	72.7	44.3	13.1	30.2
Volatile Suspended Solids	69.3	44.7	13.5	30.5

Coefficient of variation = (mean ÷ standard deviation) x 100.

f-Analyses performed on filtered aliquots.
*-Regressed values ommitted.

variation. These values, calculated for the entire data set, are exhibited in Table 8. The variation was reduced by more than 50 percent for most of the variables shown. It must be noted that the lower limit for the diurnal variation would be expected to approximate the day to day variation since the flow was only equalized within a given day, thus, day to day variations are not affected.

In examining the percent variation for the daily data, a decrease is noted in filtered BOD_5 and there are increases in suspended solids and volatile suspended solids. In the latter cases the coefficients of variation are more than doubled. (This can also be seen in the lower graph of Figure 9.) It appears that the activity in the equalization tank was extremely variable on a day to day basis.

Histograms were constructed for all variables and sample points, to determine if the distribution of the data would reveal any further insight. Smoothed frequency histograms for COD and suspended solids are shown in Figure 6. Again the diurnal data were weighted with flow before analysis and therefore represent mass and not concentration.

These figures indicate a significant reduction in the extreme values, particularly maximum values. Even in the case of BOD_5, where the mean value across the equalization tank increases by 30 mg/l, the maximum value decreased from 505 to 385 mg/l. The respective values for COD are 990 and 730 mg/l indicating a similar, although less pronounced, phenomenon. For suspended solids, peak values were reduced from 500 to 260.

COMPARISON OF PRIMARY EFFLUENTS

In examining the effects of equalization on the primary units, again the first step was to note differences in the mean value of the effluent concentrations. Table 9 exhibits these data for the diurnal series.

While the mean values decreased in all of the variables shown, the decrease was not statistically significant at a 95 percent level for the variables measuring oxygen demand. In the case of BOD_5, there exists a difference in the mean values of primary effluents at about a 70 percent confidence level. Part of this can be attributed to a small number of data points for BOD_5 and BOD_f. For BOD_f, COD and COD_f, the t-values are even lower. The differences in total organic carbon and suspended solids are more significant, primary effluent suspended solids under equalized conditions being less than 70 percent of the first phase values, and a t-value for the comparison indicating a level of confidence exceeding 99 percent.

The coefficients of variation, shown in Table 10, indicate an extreme difference in diurnal variability of the primary effluents in the two phases, demonstrating that influent to secondary and tertiary units would be equalized with respect to strength of the waste as well as flow.

This can be seen more clearly in Figure 7, which gives smoothed histograms showing the comparison of primary effluents for BOD_5 and COD. Again, these data are weighted with flow and the bi-modal distributions for Phase 1 are a direct consequence of high concentrations during the day being weighted with higher flows, and low concentrations

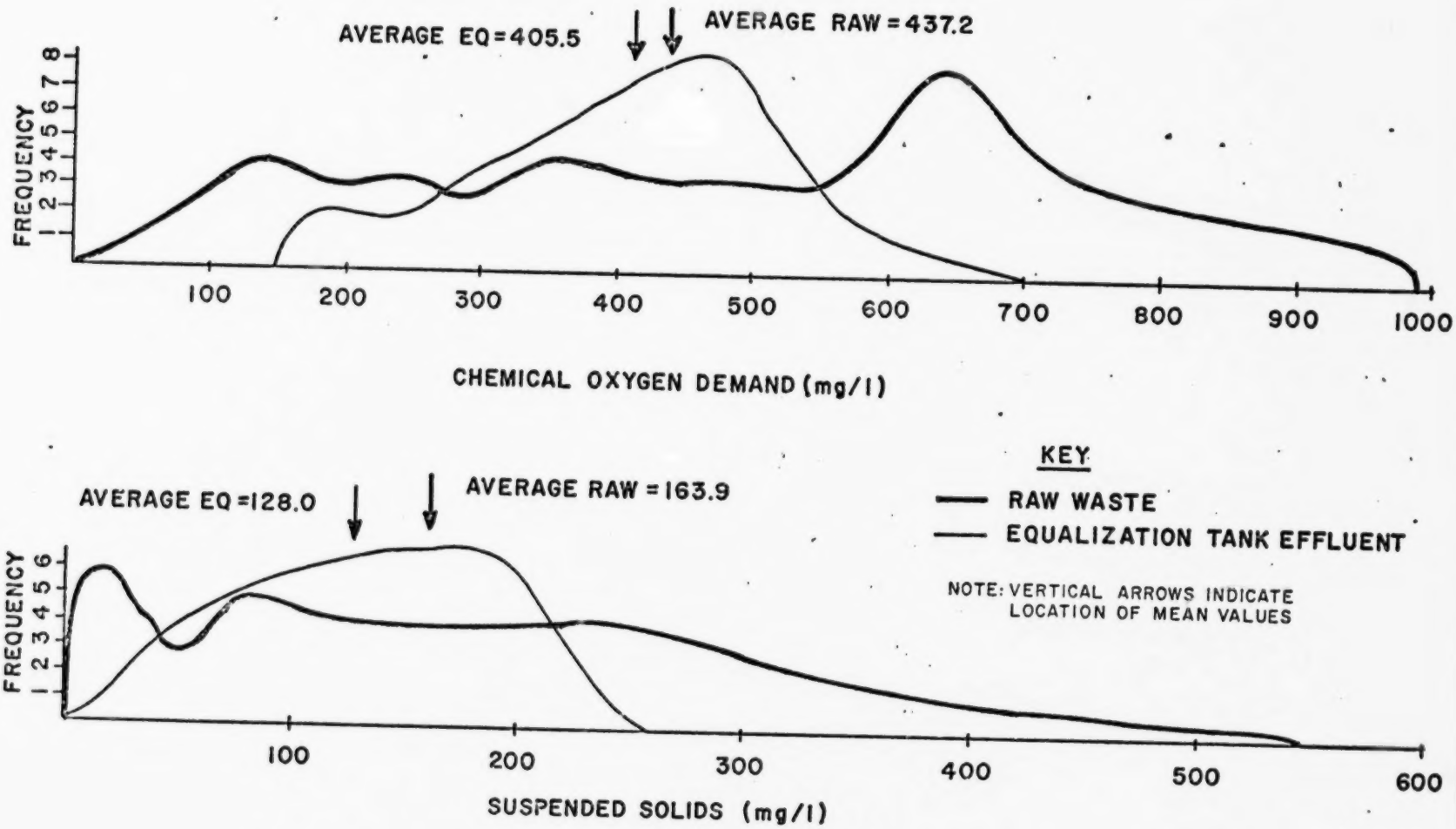

FIGURE-6-FREQUENCY HISTOGRAMS-DIURNAL SAMPLES

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TABLE 9

COMPARISON OF MEAN VALUES OF PRIMARY EFFLUENT

PHASE 1 VERSUS PHASE 2

VARIABLE	PHASE 1		PHASE 2				95% CONFIDENCE INTERVAL		
	Mean	Std.Dev.	Mean	Std.Dev.	t	ν	Lower	$(\mu_1 - \mu_2)$	Upper
Biochemical Oxygen Demand*	209.6	113.2	184.9	32.5	1.00	34	-23.6		73.1
Biochemical Oxygen Demand (f)*	105.0	64.6	93.1	15.4	0.71	26	-20.7		44.5
Chemical Oxygen Demand	355.7	179.7	337.5	90.3	0.54	71	-47.3		83.7
Chemical Oxygen Demand (f)	226.9	111.2	214.7	41.2	0.52	71	-28.5		48.9
Total Organic Carbon	120.5	59.5	97.3	16.7	2.25	71	3.0		43.4
Total Organic Carbon (f)	82.8	38.2	66.4	12.4	2.45	71	3.3		29.5
Suspended Solids	105.4	58.8	68.0	12.3	3.63	69	17.2		57.6
Volatile Suspended Solids	92.6	49.2	60.5	12.8	3.69	69	15.0		49.2

Data from diurnal sampling program.
values weighted with flow.

*Regressed values omitted.

t - Students t - statistic
ν - Degrees of freedom
f - Analyses performed on filtered aliquots

at night being weighted with low flows. This is, of course, what actually happens in municipal plants, many of which are organically overloaded (i.e., on a basis of pounds of BOD_5 in the raw waste per pound of mixed liquor suspended solids under aeration), during the day and severely underloaded at night. This must decrease the efficiency of such plants. The distribution of data for the equalized phase shows a typical bell-shaped gaussian distribution, indicating the feed to secondary units would be relatively consistent 24 hours per day. It should be noted that the maximum value of Phase 2 COD on Figure 7 consists of a single point (740). The next highest value was under 500.

Similar histograms for the daily sampling program (Figure 8) do not show these differences. The BOD_5 and COD distributions are skewed for both phases. The only difference in the two phases was that more data points were collected in Phase 1, yielding a higher mode. The location of the mean, mode and the range are the same for BOD_5 and only slightly different for COD indicating that for the daily data, primary effluent BOD_5 and COD were essentially the same for both phases.

Figure 9 shows the effects of equalization on primary suspended solids and illustrates clearly that for this variable, there is a definite improvement with equalization. In the upper histogram, mean values are almost identical, but the effect of constant flow in eliminating peak day to day values is evident. Maximum values of daily composite samples in Phase 1 ran as high as 270 mg/l primary effluent suspended solids. The maximum value for equalized phase was 130 mg/l.

The lower histogram in Figure 9 indicates the problems encountered in attempting to evaluate removal efficiencies. By comparing the raw waste with the primary effluent, one obtains only 16 percent suspended solids removal in both phases. If the primary influent (equalized waste) and the primary effluent in Phase 2 are compared the removal is 32 percent, essentially a doubling of removal efficiency, presumably caused by constant flow through the primary settling tank. (Note: The difference in percent removal values here compared to those reported in Section V is that these values include all the data, whereas some of the earlier data were removed.)

It is also interesting to note that for the daily series not only are the suspended solids in the equalization tank effluent significantly larger in mean value, but also the distribution of data is more skewed (2.4 compared to 0.3 for the raw waste, where a normal distribution has a skewness of zero) and has a larger Kurtosis (9.2 compared to 2.3 on a scale where the normal distribution has a value of 3). There is considerably more variation in the equalization tank effluent as well (coefficient of variation of 30 percent compared to only 13 percent in the raw waste).

It is clear from Figure 9 that even with such large variations in the strength of the waste, constant flow through the primary unit is able to produce a consistent effluent on a day to day basis. Thus, equalization of flow through the primary unit is effecting an equalization of waste strength in the effluent. This can be seen for all of the variables in the coefficients of variation summarized in Table 10.

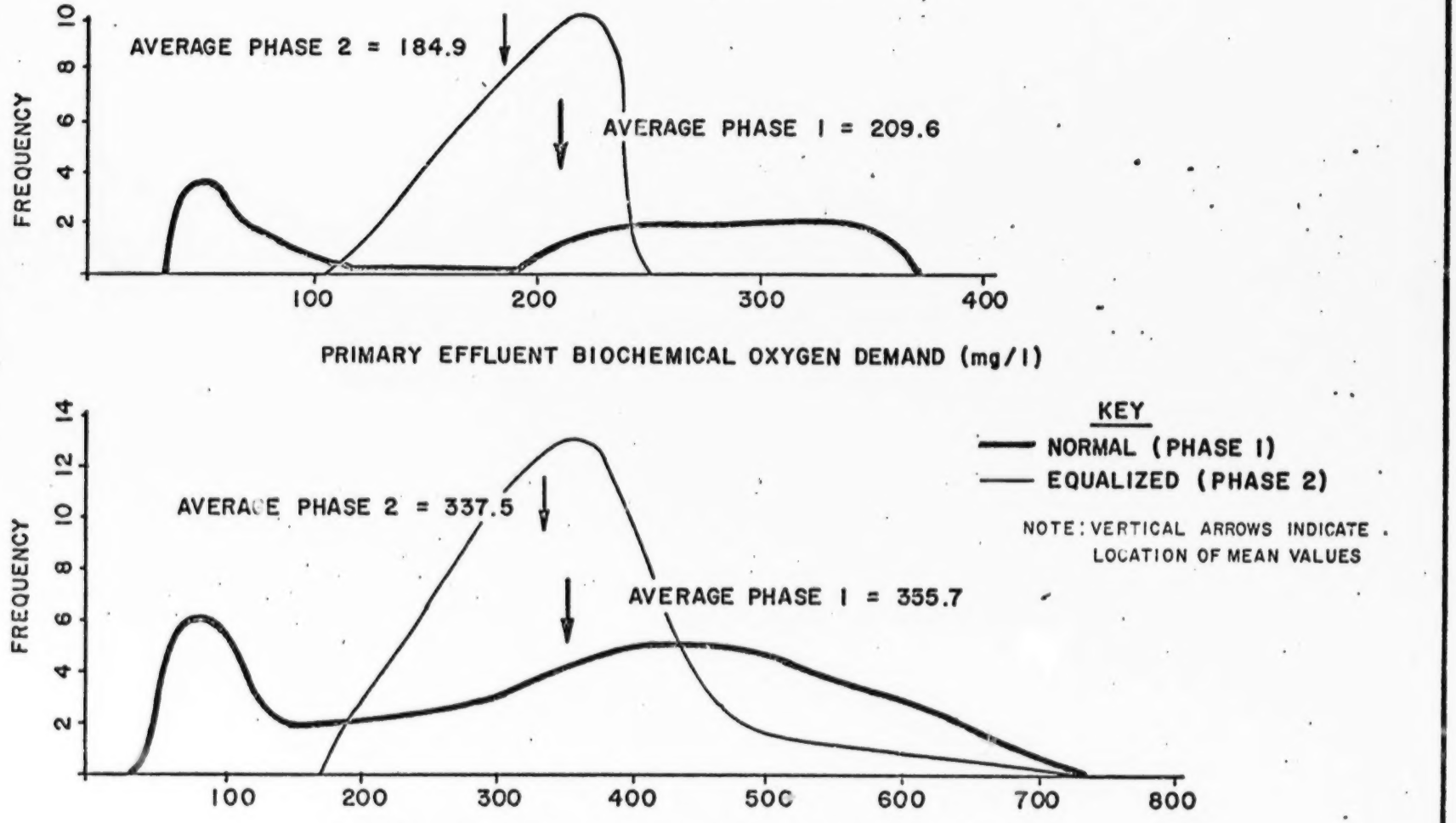
AVERAGE PHASE 2 = 184.9
AVERAGE PHASE 1 = 209.6
FREQUENCY
2 4 6 8 10
100 200 300 400
PRIMARY EFFLUENT BIOCHEMICAL OXYGEN DEMAND (mg/l)
KEY
NORMAL (PHASE 1)
EQUALIZED (PHASE 2)
NOTE: VERTICAL ARROWS INDICATE LOCATION OF MEAN VALUES
AVERAGE PHASE 2 = 337.5
AVERAGE PHASE 1 = 355.7
FREQUENCY
2 4 6 8 10 12 14
100 200 300 400 500 600 700 800
PRIMARY EFFLUENT CHEMICAL OXYGEN DEMAND (mg/l)

FIGURE 7.- EFFECT OF EQUALIZATION ON PRIMARY EFFLUENT DATA FROM DIURNAL SAMPLING SERIES

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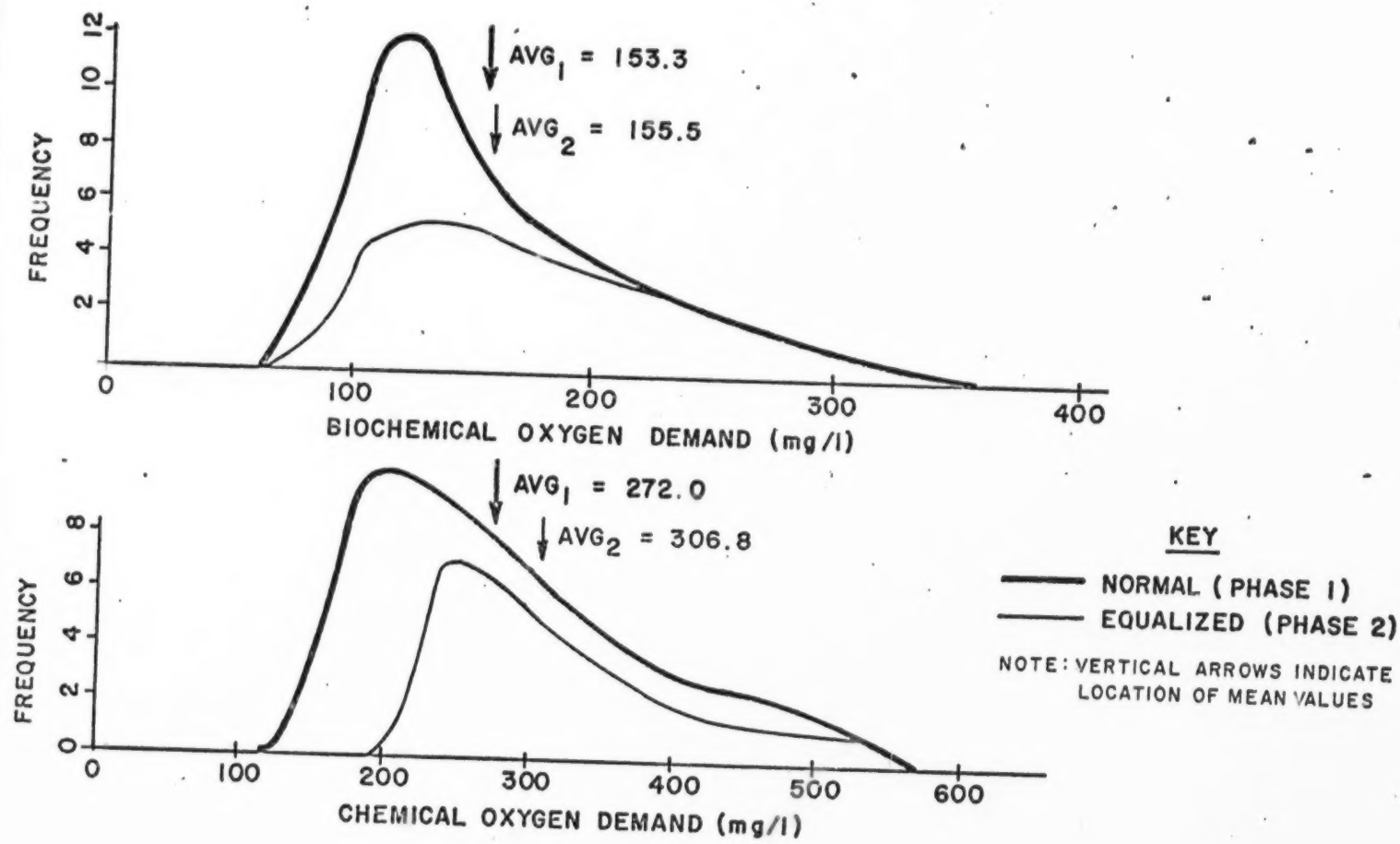

FIGURE 8-EFFECT OF EQUALIZATION ON PRIMARY EFFLUENT
DATA FROM DAILY SAMPLING SERIES

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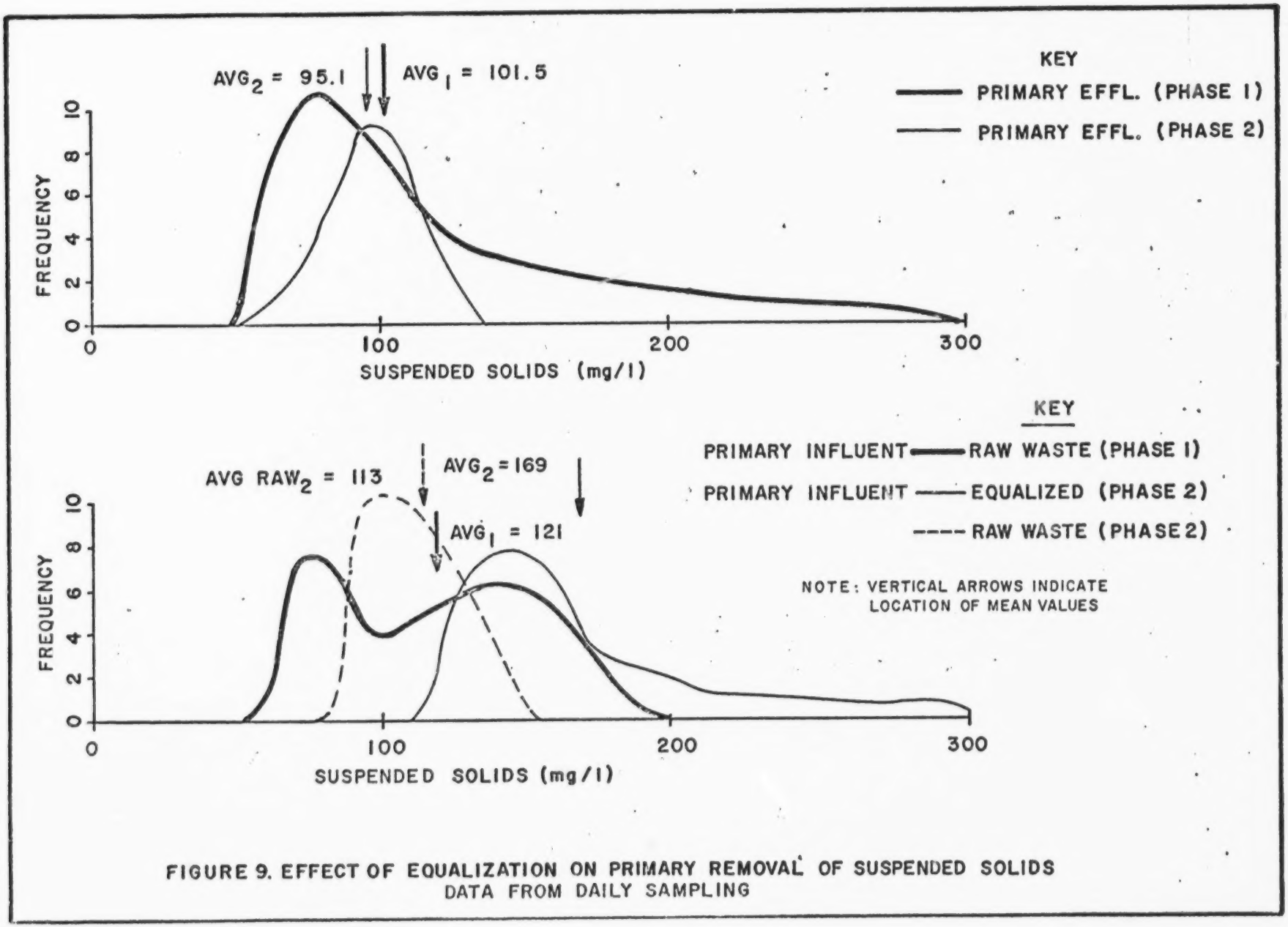

FIGURE 9. EFFECT OF EQUALIZATION ON PRIMARY REMOVAL OF SUSPENDED SOLIDS
DATA FROM DAILY SAMPLING

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TABLE 10

EFFECT ON PRIMARY TREATMENT

COEFFICIENT OF VARIATION FOR PRIMARY EFFLUENT

VARIABLE	DIURNAL		DAILY	
	Phase 1	Phase 2	Phase 1	Phase 2
Biochemical Oxygen Demand*	54.0	17.5	35.6	32.7
Biochemical Oxygen Demand (f)*	61.5	16.5	45.4	40.6
Chemical Oxygen Demand	50.5	26.7	29.3	25.1
Chemical Oxygen Demand (f)	49.4	19.1	28.2	39.0
Total Organic Carbon	49.3	17.2	24.1	21.1
Total Organic Carbon (f)	46.0	18.6	25.9	48.2
Suspended Solids	59.2	18.1	44.1	19.0
Volatile Suspended Solids	60.6	21.1	39.6	19.6

Coefficient of variation = (mean ÷ standard deviation) x 100

*Regressed values ommitted.

SECTION VII. ACKNOWLEDGEMENTS

The following individuals contributed to the completion of this Study.

ADMINISTRATION

Frank J. Drehwing, Director of Research
Michael D. LaGrega, Project Manager

ADVISORS

Amrit L. Goel, Statistics
John D. Keenan, Microbiology
M. C. Rand, Chemistry

FIELD OPERATIONS

John J. Piccirillo, Project Engineer
Orest Hrycýk, Project Chemist
Joseph Garafalo, Technician
R. Shawn O'Hara, Technician
Glenn Rosenbarker, Technician

LABORATORY

Joseph Vecchio, Director
Donald F. Beltz, Chemist
Cornelius B. Murphy, Chemist
Harry S. Pink, Chemist
Edwin Tifft, Chemist
Donald R. Brondou, Technician

COMPUTING CENTER

Robert D. Marshall, Manager
James J. McDonnell, Systems Analyst

MANUSCRIPT PREPARATION

Monica M. Newton
Caren P. Maser

ENVIRONMENTAL PROTECTION AGENCY

Richard G. Eilers, Project Officer
Charles L. Swanson, Project Officer

VILLAGE OF NEWARK

Arthur B. Carlson III, Coordinator of Public Works
George Warren, Chief Operator
Robert Young, Assistant Operator

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SECTION IX. PUBLICATIONS

The following publications summarizing some of the results and conclusions of this Study are planned:

Goel, Amrit L. and LaGrega, Michael D., "Stochastic Models for Forecasting Sewage Flows", to be presented at the Forty-First Nation Meeting, Operations Research Society of America, New Orleans, La., April, 1972.

Goel, Amrit L. and LaGrega, Michael D., "Predicting Wastewater Flow Rates by Time Series Analysis", Abstract submitted for the Forty-Fifth Annual Conference, Water Pollution Control Federation, Atlanta, Ga., 1972.

LaGrega, Michael D. and Keenan, John D., "Effects of Equalizing Sewage Flows", Abstract submitted for the Research Symposia, Forty-Fifth Annual Conference, Water Pollution Control Federation, Atlanta, Ga., 1972.

Goel, Armit L. and LaGrega, Michael D., "Predicting Biochemical Oxygen Demand from COD and TOC by the Method of Power Transformation (Paper in Preparation).

SECTION X. GLOSSARY

DEFINITIONS

Autocorrelation	-	The internal correlation (relationship) between elements of stationary time series, usually expressed as a function of the time lag between observations.
Autoregressive Process	-	A process in which the current observation depends on previous value (i.e., which has memory) and on a current random shock.
Bulking	-	The failure of the activated sludge floc to settle properly.
Centrate	-	The liquid phase (effluent) of a centrifuge.
Coccoid	-	Spherical
Coefficient of Variation	-	The ratio of the standard deviation of a set of data to its arithmetic mean, expressed as a percentage.
Degrees of Freedom	-	The number of independent values available to estimate a statistic. (e.g., a random sample of size M is said to have M-1 degrees of freedom in that there are M-1 independent deviations from the mean on which to base such an estimate.
Digester	-	A tank in which the solids resulting from the sedimentation of sewage are stored for the purpose of permitting anaerobic decomposition.
Distribution	-	The overall scattering of observed data; the distribution of a variable can be related to its probability structure.
Diurnal	-	Of or pertaining to an individual day, e.g., Diurnal variation - changes occurring from day to night.
F-test	-	A test based on statistics having the F-distribution, commonly used for comparing variances of two sets of data from Normal populations.

Filamentous Bacteria	-	Bacteria in which the cells are aligned end to end.
Gaussian (Normal) Distribution	-	The name given to a certain kind of probability distribution characterized by a bell-shaped curve.
Histogram	-	A plot of grouped data obtained by drawing rectangles whose bases coincide with the class intervals and whose heights are proportional to the class frequencies.
Hold Fast	-	A cell whose function is attachment to a solid substrate.
Hydrolysis	-	Decomposition of a compound with the addition of water.
Kurtosis	-	The relative peakedness or flatness of a distribution. The Kurtosis for the normal distribution is 3. A measure of the relative concentration of data at the center and along the tails of the distribution.
Mode	-	A measure of location defined as the value which occurs with the highest frequency.
Moving Average Process	-	A process in which a current observation is affected by random shocks that entered the system during previous times.
Non-parametric Tests	-	Tests which do not depend on the assumption of a particular type of distribution and are valid for any continuous distribution.
Statistic	-	A quantity (such as the arithmetic mean or the standard deviation) calculated from a sample.
Stochastic Process	-	A physical process which is governed at least in part by some random mechanism.
t-Tests	-	Tests based on statistics having the t-distribution.

Parameter	-	A quantity which characterizes the distribution of a random variable or a population. (e.g., The population mean and population variance are parameters characterizing the normal distribution).
Sheath	-	Tubular cover. around a trichome or filament.
Skewness	-	The lack of symmetry in a distribution (e.g., the Normal distribution, or any symmetric distribution has a skewness of zero).
Sphaerotilus Natans	-	A filamentous bacterium.
Stationary Process	-	A random process whose statistical characteristics remain unchanged as time progresses.
Sudanophilic Granules	-	Intracellular particles which adsorb Sudan Black dyes. These particles are storage depots for fatty materials.
Supernatant	-	The lighter (less dense) phase of a liquid-liquid separation.
Trichome	-	A single, long multicellular thread.
Vitreoscilla	-	A genus of filamentous bacteria.

ABBREVIATIONS

acf	-	Autocorrelation function
AR	-	Autoregressive
ARIMA	-	Autoregressive integrated moving average
ARMA	-	Autoregressive moving average
BOD_5	-	Biochemical oxygen demand (5 day, 20°C)
BOD_f	-	Biochemical oxygen demand (5 days, 20°C) in the filtered aliquoit
COD	-	Chemical oxygen demand

COD_f	-	Chemical oxygen demand in the filtered aliquot
D.O.	-	Dissolved oxygen
MA	-	Moving average
mgd	-	Million gallons per day
mg/l	-	Milligrams per liter
MLVSS	-	Mixed liquor volatile suspended solids
MLSS	-	Mixed liquor suspended solids
Q	-	Flow rate
pH	-	Negative logarithm of the hydrogen ion concentration
ppm	-	Parts per million
SVI	-	Sludge volume index
SA	-	Sludge age
SS	-	Suspended solids
VSS	-	Volatile suspended solids
TOC	-	Total organic carbon
TOC_f	-	Total organic carbon in filtered aliquot